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# A Study of Factors Influencing Weaning Weights of Beef Calves

Joe Allen Minyard

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**A STUDY OF FACTORS INFLUENCING WEANING WEIGHTS  
OF BEEF CALVES**

**BY**

**JOE ALLEN MINYARD**

A thesis submitted  
in partial fulfillment of the requirements for the  
degree Master of Science at South Dakota  
State College of Agriculture  
and Mechanic Arts

December, 1959

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**A STUDY OF FACTORS INFLUENCING WEANING WEIGHTS  
OF BEEF CALVES**


This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and acceptable as meeting the thesis requirements for this degree; but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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## INTRODUCTION

The ability of the cow to wean a heavy, vigorous and good quality calf every year is probably the most important economic trait in a beef cattle enterprise. Accomplishment of this objective is dependent on several factors. In addition to a high level of fertility, milk production and mothering qualities of the dam are important factors in profitable beef cattle production. The cow is primarily responsible for the weight of her calf at weaning time. However, the ability of the calf to make rapid and efficient gain during the suckling period will also influence weaning weight.

In South Dakota many areas are not particularly suited to commercial crop production and a very high proportion of the land in these areas is used for the grazing of livestock. The maintenance of beef cow herds for the production of feeder calves is the predominant type of operation. In a cow-calf enterprise calf weaning weight is an important factor, both to the breeder and to the feeder buying the calves for the fattening phase of beef production. It provides the breeder with information on the producing ability of his cows and information useful to the breeder and feeder on the ability of the calves to make rapid gains.

Wide variations in the weaning weight of beef calves exist in almost every herd. These variations persist despite possible continued selection and general improvement and form the basis for further genetic improvement of the trait. Because of possible climatic and management differences the variation in weaning weight over several ranches may be extremely large. However, large differences between calves within a herd are also common.

Background information necessary for the development of effective herd improvement programs include knowledge of (1) the variability present in the performance traits, (2) the relative importance of heredity on the expression of the traits, and (3) the magnitude of the influence of specific environmental factors. The improvement in livestock production is dependent, not only on how much of the individual variation is due to heredity, but also on how accurately we can recognize and make adjustments for the environmental influences. Recent studies indicate that from one-fourth to one-third of the variations in weaning weight of beef cattle are heritable. With as much as one-fourth of the total differences being heritable and with the large variation normally present, selection can be expected to bring about improvement in the trait, provided adjustment is made for the known environmental influences. Effective adjustment for the environmental factors may be made by physical control or by appropriate statistical procedures.

The purpose of this study then is to evaluate the various environmental and genetic factors that may affect the weight of beef calves at weaning.

## REVIEW OF LITERATURE

### Age of Calf

Studies by several workers have shown the growth rate of beef calves to be linear or nearly so within selected and relatively short periods from birth to eight months of age. However, when the growth rate is considered over the entire period, there may be a significant departure from linearity. Birth dates of range beef calves in South Dakota normally have a range of two to three months each year. In most herds all calves are weaned at the same time so that within a herd the calves may vary widely in age at the time they are weaned. Most methods used for adjusting weights of calves of different ages to a standard age assume linear growth during the period covered. In data containing variations in age large enough that growth rate is not linear the age adjusted weight for the very young or very old calf may be biased. If calves grow at a significantly faster rate during the first part of the suckling period than during the latter part, a decided advantage for the very young calves would be reflected in the adjusted weaning weights or the average daily gains from birth to weaning.

Brody (1921), working with dairy cows, showed that the growth rate of an animal varies with its age. The growth rate of cows increased from birth to five months of age when the gain was the most rapid during the life of the animal. From this age growth rate declined to the age of 15 months, followed by a second cycle reaching maximum gain at about 20 months of age.



Working with range beef calves raised in western South Dakota, Johnson and Dinkel (1951) showed that the growth curve approximated a straight line from birth to 155 days of age and from 155 to 225 days of age. In this study the data used were the monthly weights taken from birth to weaning on 297 high-grade and purebred Hereford calves. They found that preweaning growth is most rapid from birth to about 155 days of age and thereafter growth continues at an apparently diminishing rate. From these data separate sets of linear adjustment factors were developed for the two growth periods.

Data including weaning weights of 701 grade Hereford calves produced by 200 cows over an eight year period were analyzed by Botkin and Whatley (1953). The age of the calves at weaning varied from 120 days to 260 days. Growth curves were plotted for five groups of calves produced in three different years. They found growth to be very nearly linear during the period in which corrections were applied. The authors pointed out, however, that these growth curves were obtained from calves produced during exceptionally good years and may not be typical of growth under less favorable late summer grazing conditions.

In a study of the records of 4166 non-creep-fed calves in the Virginia performance testing program, Marlowe and Gaines (1958) employed the least squares method of analysis in estimating the effects of age of calf on growth rate. The age of the calf was arbitrarily divided into seven equal periods of 30 days in length. Changes in the growth rate were small and insignificant from 90 to 210 days of age, a slight decline was evidenced in the next period and a rather sharp decline from 241 to 300 days of age. The authors felt that the sharp decline in the latter

periods was due, in part at least, to seasonal changes.

Koch, et al. (1959) summarized the average daily gains of 1289 calves raised at the Nebraska stations from birth to midsummer and from midsummer to weaning. At the Lincoln station the average daily gains during the latter portion of the grazing season was 95 percent of the gains made during the first part of the season. The average daily gain at the Fort Robinson station during the last part of the season was only 77 percent of the earlier gain. These differences in rate of gain suggest a non-linear growth curve during the preweaning period.

#### Sex of Calf

It has long been recognized that the sex of an animal influences its growth rate. Numerous published reports indicate that the average weights of bulls and heifers differ at all ages, even when raised under similar environmental conditions. Since both sexes are not usually represented in equal numbers in all subclasses an adjustment of weights for differences due to sex is desirable for statistical analysis.

An analysis of variance study of the daily gains of 180 Hereford calves was made by Knapp and Black (1941). The calves were raised at the United States Range Livestock Experiment Station, Miles City, Montana. They were weaned at an average age of 180 days and were not grain-fed up to weaning. Sex of the calf was found to have a highly significant influence on rate of gain during the suckling period. However, the mean values for the two sexes were not presented.

Koch (1951) estimated the influence of sex on weaning weight of range beef calves by the least squares method of analysis. The data used

in this study were the weaning weights of 745 Hereford calves from Line 1 at the United States Range Livestock Experiment Station, Miles City, Montana. The calves were dropped by 180 cows during the years 1938-1948. Bull calves were 31 pounds heavier than steers and the steers were 13 pounds heavier than heifers. The large difference of 31 pounds between bulls and steers may be due, in part, to the effects of selection in deciding which male calves were to be castrated and to the physiological effects of castration. Taking the weighted average of bull and steer deviations found in this study, an average difference of 23 pounds between males and females was obtained.

Burgess, et al. (1954), in an analysis of the weaning weights of purebred Herefords at the San Juan Basin Experiment Station, Fort Lewis A and M College, Hesperus, Colorado, found that bull calves were 22 pounds heavier at weaning than heifers. Their analysis was confined to 546 conventional type Hereford calves from conventional type Hereford dams. The calves were dropped during the years 1946-1951, inclusive. The data were analyzed using the principle of least squares and the various parameters were estimated by the absorption-iterative method. The constants derived in the study were tested on the weaning weights of the 1952 and 1953 calf crops. The sex correction developed appeared to be a good fit.

Rollins and Guilbert (1954) analyzed the monthly weights to weaning on 159 calves in a study of factors affecting preweaning growth rate of beef calves. The data were gathered during the years 1944 to 1951 in the University of California purebred Hereford herd. The effects of sex were estimated by least squares analysis. They found that bull calves were 68 pounds heavier than heifers at 240 days of age. The authors felt that

this large difference was due, in part, to the older weaning age of 240 days and a possible advantage of farm over range conditions in growing a calf out to weaning.

Koch and Clark (1955) evaluated the influence of sex on weaning weight by computing the average weight for the males and females, along with the average difference, for each age of dam on a within year basis. No trend in the average difference between the sexes with increasing age of dam was apparent in these data. The sex influence was evaluated from the average difference over all ages of dam and the difference obtained was 26.2 pounds in favor of the male calves.

Chambers, et al. (1956) reported sex differences of 18 pounds at 112 days of age and 38 pounds at 210 days<sup>22</sup> of age. The differences reported were in favor of bull calves and were established by averaging the weights of each sex after adjustment to the standard age. The data affording bull-heifer comparisons included the weaning weights of 459 purebred calves produced at the Fort Reno Experiment Station, El Reno, Oklahoma from 1950 to 1955.

McCormick, et al. (1956) reported a difference of 38 pounds in bull and heifer weaning weights at 210 days of age. This difference was highly significant by standard analysis of variance techniques. The data available for this study were the records of 532 calves produced by 139 cows in a purebred Polled Hereford herd maintained under farm conditions in the Coastal Plain area of south Georgia. The calves were dropped over a period of 18 years.

Marlowe and Gaines (1958) reported a significant influence of sex on growth rate of non-creep-fed calves. Bull calves grew approximately

five percent faster than steer calves and steer calves grew about eight percent faster than heifers. Adjusted to a weaning age of 210 days the bulls were 16 pounds heavier than steers and the steers 30 pounds heavier than heifers.

In a study of the weaning weights of 255 Hereford and 212 Angus calves produced at the Arkansas station over a 13-year period, Brown (1958) averaged the weights for each sex group over all years and ages of dam. He reported differences of 82 pounds between bulls and steers and a 25 pound difference between steers and heifers among the Hereford calves. Among the Angus calves bulls were 44 pounds heavier than steers and the steers 23 pounds heavier than heifers. The author cautioned that the differences between bulls and steers were <sup>22</sup>probably biased upward substantially because of selection applied in determining which males to castrate, the physiological effects of castration and advantages in management received by the bulls.

Weaning weights of 2976 range beef calves raised at six stations in Nebraska, South Dakota and Oklahoma were analyzed by Koch, et al. (1959) to evaluate the differences between bulls and heifers in gain from birth to weaning. The average difference between the sexes varied widely among the stations. When converted to 190-day weights, the differences range from about six pounds to 42 pounds. The difference between sexes averaged over all stations was 21.5 pounds.

#### Age of Dam

Previous research has indicated that the weaning weight of a calf is greatly influenced by the age of its dam. The producing ability of a

cow in terms of calf weaning weight normally increases with increasing age up to an optimum age range and thereafter declines with age. Since the weight of a calf at weaning is dependent to a large extent on the milking and mothering ability of its dam, changes in size, weight, and physiological function associated with aging might be expected to directly influence weaning weight. In most herds, including experimental herds, the producing cows will usually vary widely in age. The actual range in cow age may be greater in some herds but rarely will all cows in a herd be of the same age. In view of the variation in cow age within most herds a suitable adjustment for these differences would be desirable.

Sawyer, et al. (1948), in a study of the weaning weight of beef calves at the Oregon station, reported that two-year-old cows weaned calves 75 pounds lighter than mature cows. The weaning weight of calves increased with increasing age of dam through eight years but then declined. After adjusting the calf weights to a standard age of 210 days the influence of age of dam on weaning weight was estimated by standard variance and covariance analysis.

Botkin and Whatley (1953) and Chambers, et al. (1953), working with weaning weights of calves produced at the Oklahoma stations, corrected the weights of calves produced by young cows to a mature cow equivalent. All cows five years old and older were considered as mature. Weights of calves from three- and four-year-old cows were adjusted to a mature cow basis by adding 35 and 15 pounds, respectively. These data did not include two-year-old dams. Correction in this manner removed 82 percent of the variance due to differences in age of dam.



Rollins and Guilbert (1954) estimated the effect of age of dam on 240-day weaning weight by comparing the ordinates of the second degree regression curves of the trait in question with respect to calving sequence as the independent variable. Calving sequence was used as an estimate of dam's age. The heifers were first bred around 24 months of age. Calving sequence values can be converted to age of dam by the addition of two to each sequence number. Calves from cows 7 to 10 years of age were 21 pounds heavier than calves from three-year-old cows, 13 pounds heavier than calves from four-year-olds and had a weight advantage of 18 pounds over calves from 12 to 14-year-old cows.

Burgess, et al. (1954), in their study of factors affecting weaning weights of beef calves, estimated the influence of age of dam on this trait. Calves from two-year-old cows were 36 pounds lighter than calves from cows six to eight years of age. Calves from three to five-year-old cows and from cows nine years old and older were lighter than calves from the six to eight-year-old cows by 16 and 31 pounds, respectively. The average weaning age was about 213 days and the average weaning weight for all calves studied was 403 pounds.

The influence of age of dam on preweaning growth was estimated by Koch and Clark (1955) using the methods developed by Lush and Shrode (1950). The age of dam effects were first estimated by comparing averages of all records made at each age (Method A). The effects were then estimated by comparison of two or more records from the same cow at different ages (Method B). Since each of these methods may be biased from the true age of dam effect, method A biased upward and method B biased downward, the true age effect would be between the two methods as  $\frac{p}{1 - p}$ , where p is

approximated by the repeatability of adjacent weaning weights. The age correction factors derived from the combined estimates are:

Age:	3	4	5	6	7	8	9	10
C. F.:	41	18	6	0	3	6	12	24

Six years of age was used as the standard age since that appeared to be the age of maximum production.

Rollins and Wagon (1956) employed the method of least squares to estimate correction factors for age of dam in two herds of grade Hereford cattle. The data analyzed in this study were the weaning weights of 577 calves produced in the herds maintained by the University of California. The two herds were comparable in all respects except that one herd (A) was maintained under optimum range conditions and the other herd (B) was operated under sub-optimum conditions. The age of dam correction factors developed for each herd were presented.

Age of dam:	3	4	5	6	7	8	9	10
herd A:	50	32	17	7	1	0	3	11
Adj. herd B:	48	29	14	4	0	0	6	17

The maximum production of the cows appeared to be reached at the seven to eight-year-old range with little difference between the herds. These factors are in reasonable agreement with others reported.

Data including the daily gains from birth to weaning of 103 pure-bred Hereford and Angus calves were analyzed by Nelms and Bogart (1956). Rate of gain was calculated by subtracting the birth weight from weaning weight and dividing by the age of the calf in days. The ages of dams were grouped as two, three, four, five to seven, and eight years or over. The data were analyzed by the method of least squares using a regression



model as described by Anderson and Bancroft (1952). The older cows, eight years or over, produced the heaviest calves at weaning. Converting the daily gains to weaning weight at 190 days of age the calves from the older cows were 25 pounds heavier than calves from the five to seven-year-olds and 35, 34 and 67 pounds heavier than calves from four, three and two-year-olds, respectively. Despite the large difference between calves of two-year-old dams and those of older cows, the effect of age of dam on rate of gain to weaning only approached significance in this study.

McCormick, et al. (1956) developed age of dam adjustment factors from their data by averaging the sex-adjusted weaning weights within age of dam class. The weights increased consistently up to eight years, fluctuated irregularly from nine to 11 years and dropped rather rapidly thereafter. In this study the eight to 11 year class represented the years of maximum production and was selected as the standard age of dam. The following additive correction factors were computed:

Age:	2	3	4	5	6	7	8-11	12	13	14	15
Factor:	107	68	42	22	17	10	0	31	41	77	57

The effects of age of dam on weaning weight were greater in this study than in most studies reported. However, the conditions under which the data were collected were considerably different from those in most of the other studies.

In their study of the preweaning growth of Virginia beef calves, Marlowe and Gaines (1958) estimated age of dam effects by conventional least squares analysis. The influence of cow age was estimated by comparing averages of all records made at each age of dam. This method, as pointed out by Lush and Shrode (1950), would bias the estimates upward from the

true age effect. However, the authors stated that the magnitude of the bias would be small in these data. Seven years appeared to be the age of maximum production and was used as the standard age in this study. Converting the daily gains to 190-day weaning weights the estimated effects computed were:

Age:	2	3	4	5	6	7	8	9	10/
Dev.:	-57	-32	-21	-15	-8	0	-12	-2	-13

The growth rate of calves from dams six to 10 years of age were not adjusted. Corrections, the above deviations with signs reversed, were applied to the gains of calves from dams which were two, three, four, five and over 10 years of age. The most important source of variation in growth rate found in this study was attributed to differences in age of dams.

The effects of age of dam on 240-day weights of 255 Hereford and 212 Angus calves were estimated by Brown (1958). Using weights that had been corrected for age, sex, and year and month of birth, the correction factors were calculated in each breed from a comparison of all records made at each age. The calves from two and three-year-old Hereford cows and two-year-old Angus cows were considerably lighter than calves from older dams. There was no apparent decline in weight of calves from the older dams. All cows four years old and older were considered mature. The difference between a mature record and the two and three-year-old records was used to standardize these young groups to a mature equivalent. Fifty-one and 44 pounds were added to the calf weights of two and three-year old Hereford cows while 57 and eight pounds were added to the weights of two and three-year-old Angus cows, respectively.

### Season of Birth

The growth rate of beef calves from birth to weaning may be influenced by the time of birth of the calf. This may be true in areas where the productivity of the pastures varies throughout the season or in areas where grazing conditions are normally poorer during the latter part of the suckling period.

Rollins and Guilbert (1954) divided the period when calves were normally dropped each year into three seasons; (1) August through November 15, (2) November 16 through February and (3) March through May. They found that season of birth had a substantial effect on rate of gain from birth to four months of age and weight at 240 days of age. Calves dropped in the fall gained 0.18 pounds per day less and calves dropped in the spring gained 0.06 pounds per day more for the first four months than calves dropped in the winter. The spring and fall calves were 39 and 16 pounds lighter at 240 days of age than were calves dropped during the winter season.

Koch and Clark (1955), utilizing data from 5952 Hereford calves raised at the United States Range Livestock Experiment Station, Miles City, Montana, estimated the influence of season of birth by regressing preweaning gain on weaning age. This type of analysis was feasible since all calves were weaned on the same day. The data were separated into subclasses of calves born in the same year from cows of the same age. The regression of gain from birth to weaning on weaning age was -0.04 pounds per day ( $\neq 0.05$ ). Two possible interpretations of this regression were suggested by the authors: (1) If calves grow linearly with age, it

indicates that calves born early in the season did not grow quite as rapidly as calves born later. (2) If growth rate declines slightly with age, a slight negative regression would be expected even though the calves were following the same growth pattern. They suggest that both of these influences were operative, a faster growth rate of young calves opposed by a seasonal advantage of the older calves. The net result of these opposing influences may be responsible for the linearity of growth observed in these data and this linear growth may not be representative of the growth pattern of calves in other localities.

The influence of time of birth on preweaning gain of calves produced at the Oregon station was estimated by Nelms and Bogart (1956). The breeding season was restricted to 90 days so the calves were dropped over a four-month period. Time of birth was arbitrarily divided into 20-day periods beginning with March 1. A significant difference in growth rate between periods of birth was found. The early calves gained at a considerably faster rate than did the calves born late. The calves born in the first part of the season gained as much as 0.38 pounds per head daily more than those born in the last part of the season, even though the breeding season was restricted to 90 days.

Marlowe and Gaines (1958) arbitrarily divided the year into four periods, winter, spring, summer and fall, and estimated the influence of season of birth on daily gain to weaning. Time of birth appeared to be of statistical and practical significance for preweaning growth rate. The average daily gain of calves born in the spring was higher than calves born in winter, summer and fall by 0.04, 0.13 and 0.16 pounds, respectively. Expressed as weaning weight at 190 days of age calves dropped in the spring

were 7.6, 25 and 30 pounds heavier than calves dropped in the winter, summer and fall.

### Repeatability of Weaning Weight

The repeatability of weaning weight has been described by Lush (1949) as the intraclass correlation of the weaning weights of calves from the same cow and is an index of the predictive value of a cow's observed record for indicating her future performance. With increased emphasis on weaning weight, resulting from the trend toward finishing and marketing beef at earlier ages and lighter in weight, efficient and early selection for improvement in the trait is desirable. Reasonably accurate estimates of the repeatability of weaning weight are important to effective selection for cow production. Estimates of repeatability of weaning weight in beef cattle generally fall in the range of 0.30 to 0.50.

Koger and Knox (1947) estimated repeatability from a study of the weaning weight records of calves produced at the experimental ranch of the New Mexico Agricultural Experiment Station from 1935 through 1945. Weaning weights were adjusted to a standard age of 205 days and for differences due to sex of calf. Age of dam effects were controlled statistically for this investigation. They found the average correlation of one year's calf weight with the next for all ages of dam was 0.49. When the average of two or more records were compared with the first calf weight, the coefficients varied from 0.51 to 0.53.

In a study of the data collected at the Nebraska stations Gregory, et al. (1950) estimated the intraclass correlation coefficients for various

combinations of production records. Their estimate of repeatability based on first and second weaning records was 0.50. The intraclass correlation of first and third weaning weight records of the same cow was 0.35 while 0.37 represented the correlation of second and third records in their data.

Koch (1951) estimated the repeatability of weaning weight from a study of the records of 745 calves from 180 high-grade Hereford cows at the United States Range Livestock Experiment Station, Miles City, Montana. The weaning weight records were collected during the period 1938 to 1948. The least squares method of estimation for multiple classifications with disproportionate frequencies was used in estimating the several factors influencing weaning weight. From this analysis the intraclass correlation among records by the same cow was estimated as 0.52.

Botkin and Whatley (1953) utilized the weaning weights of 701 calves from 200 range Hereford cows in the Oklahoma Agricultural Experiment Station herds in estimating the repeatability of weaning weight. The weights were adjusted for age of calf, sex of calf, age of dam and year effects. Repeatability of weaning weight was determined by two methods, the intraclass correlation between calves by the same cow and regression of subsequent records on earlier records of the same cow. Repeatability was estimated by the intraclass correlation as 0.43 while the regression of later records on the first gave an estimate of 0.49.

In a genetic study of weaning weights in range beef herds operated under optimum (Herd A) and sub-optimum (Herd B) nutritional regimes, Rollins and Wagnon (1956) obtained estimates of repeatability of 0.51 and 0.34, respectively. The data were standardized for differences due to year of

birth, sex, age of dam and differential pasture effects. The correction factors were estimated from the same data by the method of least squares. Data available for making the estimates were the weaning weights of 317 calves from 97 cows in herd A and 256 calves from 89 cows in herd B. The repeatability estimates were obtained by the intraclass correlation among calves from the same cow.

### Heritability of Weaning Weight

Numerous estimates of the heritability of weaning weight in beef cattle have been reported. Published reports from several experiment stations representing many different populations of cattle and a wide variety of environmental conditions indicate a considerable range in the heritability estimates obtained. Available estimates vary from 0 to 100 percent. However, most of the values appear to fall within a range of around 20 to 30 percent.

Knapp and Nordskog (1946), working with steer calves from the United States Range Livestock Experiment Station, Miles City, Montana, estimated heritability of weaning weight by two different methods: (1) half-sib correlations obtained by analysis of variance and (2) regression of progeny average on sire obtained by covariance analysis. The animals used in the study were 177 steer calves produced by 23 sires over a four-year period. Half-sib correlations obtained from an intra-year analysis gave a heritability estimate for weaning weight of 12 percent. The second method, based on the regression of the average performance of the progeny on the performance record of the sires, gave a heritability estimate of zero. When correction was made for differences in level of feeding of the



sires, the heritability estimate was found to be 30 percent. The sires were fed differently during each of the feeding years and this difference was corrected for by computing the regression of offspring on sire within groups of sires fed the same year. The above estimates were later revised by Knapp and Clark (1950) to 28 percent. The revised estimate of heritability was obtained by half-sib correlations based on an intra-year and intra-station analysis of variance. The animals used in this study were the progeny of 110 Hereford sires produced at the Montana stations.

The paternal half-sib correlation method was used in estimating heritability of weaning weight by Gregory, et al. (1950). The data were collected at the North Platte and Valentine Substations of the Nebraska Agricultural Experiment Station. Since their data were from experiments designed primarily to determine the effects of differing wintering rations on the performance of breeding cows, the analysis of variance was made on an intra-year, intra-lot basis. Because of differences in management at the two stations correlations were determined for each station. The heritability estimates obtained were 26 percent for the weaning weights of 270 calves from the North Platte station and 52 percent for 69 calves at the Valentine station.

Shelby, et al. (1955) estimated the heritability of weaning weight from a study of the records of 635 Hereford steer calves raised at the United States Range Livestock Experiment Station at Miles City, Montana. The steers were from 88 sires mated to grade Hereford cows. Heritability was computed by the method of paternal half-sib correlation on an intra-year and intra-line basis. Their estimate was 23 percent, which is in close agreement with the estimate of 26 percent reported by Gregory, et al.



(1950) at their North Platte station and an estimate of 28 percent by Knapp and Clark (1950).

In an extensive investigation of economic characteristics in beef cattle, Koch and Clark (1955a) obtained an estimate of heritability from a paternal half-sib analysis of variance. The data available for this study were the weaning weights of 4553 calves raised at the United States Range Livestock Experiment Station, Miles City, Montana. The weaning weights were accumulated over the period 1929-1951 from 137 different sires. The authors reported a heritability estimate of 24 percent for weaning weight of range beef calves.

Koch and Clark (1955b), in another study of economic characteristics in beef cattle at the Miles City station, obtained heritability estimates for weaning weight using the method of parent-offspring regression. The regression of offspring on dam was obtained from an analysis of the records on 4234 calves and their 1231 dams. The year effect and age of dam effect were eliminated by grouping pairs of records into subclasses according to the years the cows were born and the years the calves were born. The heritability estimate obtained by this method was 11 percent. In this study the regression of offspring on sire was also used to estimate heritability of weaning weight. The records of 85 sires and their offspring were available. The progeny average was regressed on the sire's record after grouping the data into subclasses according to the year the sire was born and the year the calves were born. From the offspring-sire analysis their estimate of heritability for weaning weight was 25 percent. This estimate is in agreement with most published heritability estimates for the trait under range conditions.

In a study of the weaning weights on 646 calves sired by 62 bulls, Dinkel and Musson (1956) reported that about 36 percent of the individual differences in weaning weights are inherited. The data used in the study were collected through the South Dakota Extension Service Demonstration Project on 11 ranches over a seven-year period. Because of large environmental differences from year to year and ranch to ranch the analysis was made by comparing sires in the same year on each ranch. Part of these data are used in the present investigation.

Rollins and Wagon (1956) estimated the heritability of weaning weight in two experimental range herds operated under optimum and sub-optimum range conditions. Estimates within each herd were computed by regression of offspring on dam and by the paternal half-sib correlation method. The data were standardized for differential effect of pasture, year, sex, age of calf and age of dam. The heritability estimates obtained were inconsistent. From offspring-dam regressions the estimates in the optimum and sub-optimum herds were 84 and -13 percent, respectively. The paternal half-sib correlation method gave estimates of 9 and 54 percent from the same data. The authors considered the best estimate of heritability of weaning weight to be an average of the two paternal half-sib estimates. The average value was 30 percent.

McCormick, et al. (1956), studying the performance of purebred Polled Hereford cattle at the Georgia Experiment Station, reported heritability estimates for males and females of 33 and 26 percent, respectively. Their estimates were made from paternal half-sib correlations of 210-day weaning weights. All weights were adjusted for differences in sex and age of dam.

The heritability of weaning weight of range beef calves was estimated at 30 percent by Chambers, et al. (1958). Their estimate was obtained from an intra-sire, intra-season regression of the heifer's first record on that of her dam. The data which afforded this estimate included 59 daughter-dam pairs from a high-grade Hereford herd maintained at the Fort Reno Experiment Station, El Reno, Oklahoma. The herd is maintained primarily for long-time management studies.

Brown (1958), working with the weaning weights of Hereford and Angus calves at the Arkansas station, reported heritability estimates, based on paternal half-sib correlations, of 26 and 11 percent, respectively. However, the paternal half-sib estimates were based on a relatively small number of sires. The analysis was made on weights adjusted to a standard age of 240 days and for differences due to sex, year and season of birth of calf and age of dam.

## SOURCE OF DATA

The data used in this study were the weaning weights of purebred Hereford and Angus calves collected through the South Dakota Extension Service Demonstration Project in cooperation with breeders throughout the state.

Organized production testing of beef cattle in South Dakota was initiated in 1950 by the Animal Husbandry personnel of the South Dakota Extension Service with six ranchers taking part. The cooperative project was set up to demonstrate the value of performance testing as a practical method of improving the producing ability of beef cattle without sacrificing quality. During the first years of the testing program post-weaning gain records were emphasized. However, weaning weights as well as rate of gain records have been obtained in most cooperating herds during the past four years.

The weaning weights of 2351 calves sired by 120 bulls were available from twenty cooperating herds. Thirteen of the herds were Hereford and seven were Aberdeen-Angus. The data were collected from 1951 through 1957. However, more than 93 percent of the records were obtained in 1955 to 1957, inclusive. Fifteen of the cooperating herds, supplying 93 percent of the total records, were located in the range areas of central and western South Dakota. Five herds, contributing seven percent of the data, were located in the farming area of eastern South Dakota. The number of weaning weight records collected in individual herds varied from 24 to 455.

Since the herds were distributed over most areas of the state, climatic conditions and management practices under which the calves were

produced varied widely. In general the climate of South Dakota may be characterized as continental and subhumid, with rather extended periods of drought being common, particularly in the western areas. The average annual rainfall varies from less than 14 inches per year in northwestern South Dakota to 24 inches per year in the southeastern part of the state. Extremes of temperature are quite common. Summer temperatures above 100 degrees may be contrasted with midwinter readings well below zero.

Western South Dakota is largely native range land of mixed prairie grasses and is primarily suited to the production of range beef cattle and sheep. Eastern South Dakota is primarily a farming area with smaller units and beef cattle production is usually a part of a diversified operation. In this area beef cattle are produced on restricted acreage with more need for supplemental feeding.

Most of the calves in this study were born from February through June with very few calves being dropped during the remainder of the year. Of the 2351 calves studied, 17 were dropped during the months of July and August. Only six calves were born in October, November and December. The calves were weaned from about mid-October to December 1 with a few late summer calves being weaned in early spring, particularly in the eastern South Dakota herds. The average weaning age of all calves in the study was 203 days.

Weaning weight averages by ranch and year are presented in Table I. The weights are adjusted to a constant age of 190 days for differences due to sex of calf and age of dam. The adjustments for age of calf, sex and age of dam which were applied are discussed in detail in the appropriate sections of this manuscript. The means in Table I show a rather wide

range in calf weaning weight among the ranches as indicated by the mean weight of 357 pounds for ranch 7 and the mean weight of 495 pounds for ranch 6. Year differences were not as large as were the differences among ranches. Weaning weights in these data varied from a high of 463 pounds in 1951 to a low of 399 pounds in 1952. However, the means for these two years are based on records from only one ranch and may not be a true indication of year differences. Year differences from 1953 to 1957 were quite small, ranging from an average of 420 pounds in 1955 to an average of 445 pounds in 1957.

Sire differences in the average weaning weight of their offspring are presented in Table II. The means presented indicate considerable variation among the sires in their ability to produce heavier calves at weaning. The means range from a high of 544 pounds for sire 082 to a low of 345 pounds for sire 049.

TABLE I. RANCH AND YEAR MEANS

Ranches	Years							All Years
	51	52	53	54	55	56	57	
01	463	399	405	432	455	429	418	429
02					446	417	437	431
03						454	427	440
04							427	427
05						470	393	425
06							495	495
07							357	357
08			464			486	471	476
09					411	391	422	410
10							375	375
11					410	465	482	452
12				444	420		495	451
14							446	446
15							475	475
16							447	447
17						440	404	423
18						458	477	465
19							424	424
20							406	406
21			464			437	429	436
All Ranches	463	399	438	439	420	439	445	

TABLE II. SIRE MEANS

Sire	No. of Progeny	Weaning Weight (lbs.)	Sire	No. of Progeny	Weaning Weight (lbs.)	Sire	No. of Progeny	Weaning Weight (lbs.)
001	59	422	042	26	394	083	8	523
002	5	450	043	58	414	084	8	478
003	7	425	044	65	406	088	29	447
005	37	430	045	7	436	089	10	467
006	15	445	046	22	436	090	9	436
007	23	464	047	26	418	091	9	432
008	15	414	048	40	381	092	7	500
009	31	435	049	8	345	093	9	478
010	14	416	050	55	451	094	6	480
011	15	399	051	19	414	095	8	436
012	20	423	052	114	450	096	3	502
013	3	446	053	10	463	097	27	436
014	8	430	054	23	400	098	4	485
015	10	440	055	29	419	099	5	476
016	45	429	056	81	451	100	5	450
017	5	453	057	48	471	101	6	434
018	10	416	058	23	435	102	5	457
019	7	451	059	25	522	103	12	420
020	11	423	060	3	467	104	5	451
021	5	438	061	25	476	105	7	390
022	36	434	063	37	436	106	4	400
023	41	446	064	53	464	107	41	464
024	42	433	065	5	456	108	17	456
025	29	417	066	3	423	109	18	461
026	35	434	067	7	416	110	15	456
027	11	454	068	4	435	111	7	435
028	12	393	069	4	417	112	21	472
029	5	423	070	24	424	113	4	468
030	5	372	071	9	424	114	21	485
031	21	491	072	25	427	115	11	397
032	3	526	073	45	460	116	20	432
033	26	357	074	45	429	117	3	467
034	18	358	075	27	416	118	16	428
035	8	448	076	29	420	119	8	375
036	27	490	077	15	487	120	7	392
037	16	473	078	16	496	121	4	452
038	29	474	079	5	472	122	4	476
039	11	468	080	16	483	123	39	433
040	9	379	081	12	483	124	57	432
041	11	392	082	14	544	125	10	439



## STATISTICAL ANALYSIS

### Age of Calf

The age at weaning of calves included in the study varied from 82 days to a maximum age of 334 days with an average weaning age of 203 days. Two methods of calf age adjustment were evaluated. One method evaluated in this study has been advocated by some workers (Brody, 1945) as being accurate and practical and is based on the growth rate of the individual calf. By this method the 190 day age adjusted weaning weight is computed using the following equation:

$$\text{Age Adjusted Weight} = \frac{\text{Actual Weight} - \text{Birth Weight}}{\text{Actual Age}} \times 190 + \text{Birth Weight}$$

Since birth weights were not available from these data, a constant birth weight for each sex was used. A review of the literature (Botkin and Whatley, 1953; Burris and Blunn, 1952; Gregory, Blunn and Baker, 1950; Koch and Clark, 1955; and Koch, et al. 1959) indicates the differences between sexes for birth weight generally fall in the range of 4 to 6 pounds. The average of the reported birth weights of bull calves appeared to be approximately 70 pounds. The mean birth weight of heifer calves has been reported at about 65 pounds. These values were used in making the age of calf adjustments. This method of age adjustment is subsequently referred to as age adjustment No. 1. The second method of calf age adjustment used in this study was developed by Johnson and Dinkel (1951) and the factors were computed by linear regression of weight on age. The multiplicative adjustment factors were calculated from weaning weights of calves raised under conditions similar to those of this study. The

appropriate factors are calculated using the formula:

$$\text{Factor} = \frac{\text{Standard Age} - \text{Age Intercept}}{\text{Actual Age} - \text{Age Intercept}},$$

where the age intercept is the intercept of the regression line on the age axis. This method of calf age adjustment is referred to as age adjustment No. 2.

To compare the effectiveness of the two methods of age adjustment three sets of the weaning weight data, no age adjustment, adjustments No. 1 and No. 2, were subjected to two methods of statistical analysis. Sex of calf and age of dam adjustment factors were developed from the data for each method of age adjustment. The sex of calf and age of dam adjustment factors used for the unadjusted weaning weights were, in each case, the average of the two factors developed for age adjusted weights No. 1 and No. 2.

The weaning weight records from the two breeds represented in these data were pooled for comparing the two methods of age adjustment and for estimating the effects of sex, age of dam and season of birth. Separate analyses were not made for each breed because the number of records available from Angus herds was not considered adequate to give reliable results. Data available for the age of calf analysis included 361 Angus records while Angus calves accounted for only 111 of the 1270 records used in the sex of calf analysis. One method of estimating age of dam effects utilized 912 weaning weight records including only 64 Angus. Since there were so few Angus records, deletion or addition of these records would have little effect on the results unless differences between breeds were quite large. Preliminary examination of the means did not indicate large differences between the breeds with respect to these factors.

Age of calf was arbitrarily divided into twelve equal periods of 20 days in length and the differences among age groups were analyzed by conventional analysis of variance. Identical analyses were made on each of the three sets of data. Sums of squares were calculated for ranches, years and age of calf with the remaining variance being pooled for the error term.

The two methods of calf age adjustment were further compared by calculating the regression of weight on age and the correlation of weight with age at weaning. The weights were divided into subclasses according to ranch, year and month of birth and the regression and correlation coefficients were then calculated on an intraclass basis. Again, the computations made were identical among the three sets of data being compared.

#### Sex of Calf

Two methods of adjustment of calf weaning weights for sex differences have generally been used. One method is to add or subtract the average difference in age constant weight between bulls and heifers. Another method is to multiply the weight to be adjusted by the ratio of the average weights of the two sexes, or by the ratio of the standard deviations of the two sexes. Both methods make the same adjustment in the mean values. However, a multiplicative adjustment also alters the variance of the adjusted group, whereas the additive adjustment does not. The choice of method for sex adjustment should be based on an evaluation of mean differences between the sexes, the ratio of the means, the variation within each sex, and whether the variation is associated with

the mean. In addition to accuracy of the adjustment applied, convenience and simplicity of the method should warrant some attention in making the final selection.

It has been shown by Mason, et al. (1958) and Koch, et al. (1959) that the mean and variance can both be adjusted by an equation of the form

$$\hat{B} = \bar{B} / \frac{\sigma_B}{\sigma_H} (H - \bar{H}),$$

where  $\hat{B}$  is the adjusted weight,  $\bar{B}$  is the average weight of the bull calves,  $\sigma_B/\sigma_H$  is the ratio of the standard deviations of weaning weight within each sex,  $H$  is the actual and  $\bar{H}$  the average heifer weaning weight. It can be seen from the above equation that if the standard deviation of the two sexes are equal the ratio  $\sigma_B/\sigma_H$  becomes unity and the weights are adjusted by simply adding the difference between the two sexes. If the coefficients of variation,  $C = \sigma/\bar{x}$ , are equal, then the appropriate adjustment is the ratio of the mean values for the two sexes.

The data available for the sex of calf analysis included the age adjusted weaning weights of 1270 calves. Only those records from age of dam classes with three or more calves of each sex and from ranches with three or more age of dam classes were used in this analysis. The weights were grouped by ranch, year and age of dam subclasses and the influence of sex of calf was estimated within subclasses. The mean squares, standard deviations and coefficients of variation were calculated within ranch-year subclasses.

The standard deviations of the two sexes did not differ greatly and the coefficients of variation were equal. Each method of sex adjustment,

simple additive and multiplicative ratio of means, was applied to the data to evaluate their effectiveness under these conditions of variance and mean relationship. After applying the two types of sex adjustment each group of data was analyzed within ranch, year and age of dam subclasses just as the unadjusted data had been.

#### Age of Dam

The weaning weights of 2023 calves, adjusted for differences due to age of calf and sex of calf, were suitable for use in estimating the influence of age of dam. Only those records from age of dam classes having three or more calves and from ranch-year subgroups with three or more age of dam classes were used. The data were grouped into subclasses according to ranch and year and the age of dam mean square was computed within the ranch-year subclasses.

Two methods of computing adjustment factors for differences due to age of dam are in general use. One method is to compare the averages of all records made at each age. A second method is to compare the weaning weight records of consecutive calves from the same cow. Lush and Shrode (1950) have shown that in non-experimental data both methods may be biased from the true age effect by concurrent selection practiced in the herds. However, the biases are in opposite directions, adjustment factors calculated by the first method being biased upward and factors developed by the second method biased downward from the true age of dam effect. The true age effect has been shown to lie somewhere between the two estimates, the exact value depending on the repeatability of adjacent weaning weights.

Both methods were used in estimating the influence of age of dam. By the first method the average weaning weights were calculated for each age of dam within ranch and year and then an overall average was computed for each age of dam by combining the ranch and year values. By the second method all cows having records at two or more consecutive ages were selected and the differences computed. Data available for estimating the age of dam influence were 456 pairs of records representing 378 different cows. Since adjacent weaning weight records of the same cow must necessarily fall in different years, the records were adjusted for year differences by applying an additive factor developed from these data (Table III).

TABLE III. ADDITIVE YEAR ADJUSTMENTS

Ranch	Years		
	1955	1956	1957
1	- 24	- 02	/ 21
2	--	/ 13	- 16
3	--	- 13	/ 12
5	--	- 36	/ 27
8	--	- 10	/ 07
9	/ 04	/ 21	- 16
11	/ 48	- 15	- 41
12	--	/ 31	- 41
18	--	/ 10	- 14
21	--	/ 01	- 02

Table IV shows the number of cows having calves at each age and the number of cows having calves at each pair of ages.

TABLE IV. NUMBER OF RECORDS USED IN ESTIMATING  
THE INFLUENCE OF AGE OF DAM

Method A		Method B	
Age of Dam	Cows having calves at each age	Age of Dam	Cows having calves at each pair of ages
2	87	2 - 3	19
3	247	3 - 4	64
4	314	4 - 5	94
5	326	5 - 6	91
6	263	6 - 7	68
7	224	7 - 8	47
8	165	8 - 9	37
9	130	9 - 10	36
10	98		
11	80		
12	43		
13 & up	46		

#### Season of Birth

In estimating the effect of season of birth on the weaning weight of beef calves by conventional analysis of variance it is difficult if not impossible to obtain the estimate free of calf age effects since season of birth is confounded with calf age. When all calves in a herd are weaned on the same day, the younger calves are necessarily late-season calves

while the older calves must have been born early in the year. In an effort to minimize this relationship the weights were adjusted for age of calf and further standardized to a bull calf basis from an eight-year-old dam.

The weaning weights were arbitrarily divided into twelve groups or seasons representing the month in which the calf was born. The data were divided into subclasses according to ranch and year and season differences were then analyzed within subclasses. With the data grouped in the same fashion the regression of weaning weight on month of birth was calculated on an intraclass basis.

#### Repeatability of Weaning Weight

The weaning weights of 866 calves from 378 cows were analyzed in estimating the repeatability of weaning weight. The data used were restricted to the records of cows having produced at least two consecutive calves during the period studied.

The weights were adjusted for differences due to age and sex of calf and for year effects. The analysis of variance was made on an intra-ranch basis. Repeatability of weaning weight was calculated as the ratio of variance between cows to the total variance, repeatability =  $\frac{\sigma_D^2}{\sigma_D^2 + \sigma_E^2}$ . The upper and lower limits of the repeatability estimate were calculated according to Fisher (1950).

#### Heritability of Weaning Weight

The heritability of weaning weight was estimated by the paternal half-sib correlation method as outlined by Lush (1940). The data available for the half-sib analysis included the weaning weights of 2351 calves.



As indicated earlier, the data were collected on twenty ranches during the period 1951 to 1957 inclusive. One hundred and twenty sires were represented. Some sires were used in more than one year, however, a sire that was used in more than one year was considered a different sire each year. Each yearly sample would be an unbiased estimate of sire differences. In computing the standard error of the intraclass correlation only the actual number of sires used was considered. The weaning weights were adjusted to a constant age of 190 days by using the multiplicative adjustment factors developed by Johnson and Dinkel (1951). The weights were also adjusted for differences in sex of calf and age of dam. The sex and age of dam adjustment factors used were developed from these data.

The records were grouped into ranch-year subclasses and were analyzed on an intraclass basis. The components of variance were estimated from this analysis. Methods of estimating variance components with unequal subclass numbers have been discussed by Hazel, et al. (1943), Henderson (1953), and Snedecor (1956).

To obtain the components of variance the intraclass variance must be partitioned into two mean squares, between sires and within sires. The estimate of the additive genetic portion of the variance is obtained from the sire component. Under the conditions of random mating, the genic values of half-sibs are correlated by one-fourth, each having received a sample half of their sire's inheritance. The dominance deviations of half-sibs are uncorrelated and epistatic deviations are correlated by an undetermined but small amount. According to Koch and Clark (1955) the probability that an epistatic effect requiring  $n$  non-allelic genes will be correlated between half-sibs would be  $(1/4)^n$ . If the number of genes

affecting the trait is at all large, the effect of epistasis would be extremely small and negligible. If epistatic effects are small enough to be unimportant and the environmental correlations among half-sibs have been adequately discounted, the expected value of the sire component under random mating is  $\sigma_s^2 = 1/4 \sigma_G^2$ . The expected value of the within sires mean square would be  $\sigma^2 = 3/4 \sigma_G^2 + \sigma_E^2$ . The intraclass correlation among half-sib groups in an infinite population is  $\frac{\sigma_s^2}{\sigma_s^2 + \sigma_E^2}$ . The additive genetic portion of the total variance (heritability) is estimated by multiplying the intraclass correlation by four,  $h^2 = \frac{4 \sigma_s^2}{\sigma_s^2 + \sigma_E^2}$ .

Several methods of computing the fiducial limits for the paternal half-sib correlation estimates of heritability have been discussed by Knapp and Nordskog (1946), Crump (1951) and Fisher (1950). The fiducial limits presented were obtained using the method described by Crump (1951). The quantities necessary for computing the limits by this method are F, the ratio  $\frac{\sigma_E^2 + k \sigma_s^2}{\sigma_E^2}$  obtained from the analysis of variance table;  $F_{.05}$ , the entry in a 5 percent F-table for degrees of freedom, n and  $n_2$ ; and  $F'_{.05}$ , the corresponding entry for degrees of freedom, n and  $\infty$ . The value k is the average number of offspring per sire and with data of unequal numbers the correct average has been shown by Snedecor (1956) to be

$$k = \frac{1}{a - 1} \left( n - \frac{\sum n_1^2}{n} \right),$$

where a is the number of sire groups and  $n_1$  is the number of calves in a sire group. The approximate fiducial interval of the intraclass correlation can be obtained by multiplying the correlation by  $\frac{1}{L}$  to obtain the

lower limit and by  $\bar{L}$  to obtain the upper limit where

$$\underline{L} = \frac{\frac{F}{F_{.05}} - 1}{F'_{.05} \frac{F}{F_{.05}} - 1} \quad \text{and} \quad \bar{L} = \frac{\frac{F}{F_{.95}} - 1}{F'_{.95} \frac{F}{F_{.95}} - 1}.$$

The limits of the intraclass correlation are multiplied by four to obtain the upper and lower limits of the heritability estimate.

## RESULTS

## Age of Calf

Weaning weight averages by age of calf group for each of the three sets of data are presented in Table V. The range in age was from 82 days to 334 days with a mean weaning age of 203 days. With no calf age adjustment applied the positive relationship between weaning weight and age is apparent. The unadjusted weaning weight means varied from a low of just over 300 pounds for the youngest calves to a high of 578 pounds for the oldest group. The application of age adjustment No. 1 (adjusted weaning weight =  $\frac{\text{actual weight} - \text{birth weight}}{\text{actual age}} \times 190 / \text{birth weight}$ ) appeared to over-adjust the weights of the very young and fall short of adequate adjustment for the oldest calves. This tendency is indicated by the rather sharp decline in the means from the young calves to the oldest. The means for age adjustment No. 2 (adjusted weaning weight = actual weaning weight X appropriate factor of Johnson and Dinkel) show a much narrower range and a reverse of the weight-age relationship observed following adjustment No. 1. Here the relationship between weaning weight and age at weaning appears to be quite small and positive.

Table VI shows the analysis of variance and test of significance of weaning weight and weaning age for each of the three groups of data. The F value is indicated only for the effect of age of calf on weaning weight and is significant at the 0.01 level of probability in all three groups of data. The effectiveness of the two methods of calf age adjustment may be indicated by the relative size of the age of calf mean squares.

TABLE V. AGE OF CALF MEANS

Calf Age (days)	No. of Animals	Weaning Weight (lbs.)		
		No Age Adj.	Age Adj. No. 1	Age Adj. No. 2
80 - 99	7	303	526	470
100 - 119	21	304	445	407
120 - 139	55	301	453	416
140 - 159	144	377	453	414
160 - 179	312	402	440	418
180 - 199	525	441	442	440
200 - 219	577	472	440	455
220 - 239	406	473	411	439
240 - 259	214	503	412	450
260 - 279	63	517	397	445
280 - 299	22	538	390	451
300 & up	5	578	385	465

By using age adjustment No. 1 the original age of calf mean square was reduced by 85 percent. Age adjustment No. 2 reduced the age of calf mean square by 90 percent.

The average regression of weaning weight on age at weaning and correlation of weight with age for each of the three sets of data are presented in Table VII. Further indications of the effectiveness of the two methods of age adjustment can be seen by comparing the intraclass regression of weaning weight on age for the three groups. If the age of calf adjustment applied is completely adequate, then the age adjusted

weaning weights should be independent of calf age. Changes in the relative size of the regression and correlation coefficients should be useful in evaluating the effectiveness of the age adjustment applied. Both methods of adjustment show a substantial reduction in the regression and correlation coefficients. The greatest reduction in the intraclass coefficients is shown for age adjustment No. 2; however, differences between the two methods in this respect are quite small.

TABLE VI. EFFECTIVENESS OF TWO METHODS OF CALF AGE ADJUSTMENT

Source of Variation	d.f.	Sums of Squares	Mean Squares	F
No Calf Age Adjustment Applied				
Total	2350	11,882,377		
Ranches	19	1,342,014	70,632	
Years	6	138,250	23,042	
Age of Calf <sup>1/</sup>	11	4,466,485	406,044	158.3**
Error	2314	5,935,628	2,565	
Calf Age Adjustment No. 1				
Total	2350	7,415,226		
Ranches	19	1,918,597	100,979	
Years	6	385,386	64,231	
Age of Calf	11	660,438	60,040	46.9**
Error	2314	2,964,421	1,281	
Calf Age Adjustment No. 2				
Total	2350	7,535,867		
Ranches	19	1,261,559	66,398	
Years	6	225,314	37,552	
Age of Calf	11	468,587	42,597	17.7**
Error	2314	5,580,407	2,412	

<sup>1/</sup> Age of calf was arbitrarily divided into 12 equal periods of 20 days in length.

\*\* Highly Significant ( $P < 0.01$ )

TABLE VII. REGRESSION OF WEIGHT ON AGE AND CORRELATION OF WEIGHT WITH AGE WITHIN RANCH, YEAR AND SEASON

Source of Variation	d.f.	Age X	XY	Weight Y	$b_{yx}$	$r_{xy}$
No Calf Age Adjustment Applied						
Total	2350	2,625,498	3,352,520	11,882,377	$f1.28$	$f.60$
Ranch-Year-Season Subclass	188	2,312,741	2,977,814	8,186,485		
Within Ranch-Year-Season	2162	311,757	374,706	3,695,492	$f1.20$	$f.35$
Calf Age Adjustment No. 1						
Total	2350	2,625,498	-1,167,376	7,415,226	- .44	-.26
Ranch-Year-Season Subclass	188	2,312,741	-1,236,975	3,620,229		
Within Ranch-Year-Season	2162	311,757	69,599	3,794,997	$f.22$	$f.06$
Calf Age Adjustment No. 2						
Total	2350	2,625,498	748,050	7,535,867	$f.28$	$f.17$
Ranch-Year-Season Subclass	188	2,312,741	698,376	3,392,297		
Within Ranch-Year-Season	2162	311,757	49,174	4,143,570	$f.16$	$f.04$



### Sex of Calf

The weaning weights used for the sex of calf analysis were adjusted to the constant age of 190 days by the method of Johnson and Dinkel (1951), age adjustment No. 2. Table VIII gives the analysis of variance for weaning weight unadjusted for differences due to sex of calf. The between sex mean square within ranch and year was significant at the 0.01 level of probability. In seeking the most accurate and practical means of estimating sex differences it is important to know the relationship of sex differences at weaning to age of dam. To evaluate this relationship the age of dam by sex interaction was computed within ranch and year. The interaction mean square was not statistically significant.

The weaning weight averages for the bull and heifer calves and the differences between sex means by age of dam is given in Table IX. Sex differences vary among the age of dam groups from a 2.4 pound advantage for the heifers in the 12-year-old and over group to a 55.6 pound advantage for the bull calves from nine-year-old dams. The sex averages for the 12-year-old group are based on very small numbers and are probably not reliable estimates of the true means. The reason for the relatively small difference between the two sexes from three and five-year-old dams is not known. Differences in weaning weight of the two sexes appeared to be slightly greater for the eight to 11-year-old age of dam groups. However, the differences lacked significance and age of dam was disregarded in computing the sex adjustment.

TABLE VIII. ANALYSIS OF VARIANCE OF SEX DIFFERENCES

Source of Variation	d.f.	Mean Square	F
Total	1269		
Ranch-Year-Age of Dam	85	18,694	
Sex Within Ranch-Year	22	25,188	12.86**
Age of Dam X Sex Within Ranch-Year	64	576	
Error	1098	1,959	

\*\* Highly Significant ( $P < 0.01$ )

TABLE IX. SEX DIFFERENCES WITHIN AGE OF DAM CLASSES

Age of Dam	Bulls		Heifers		Average Difference (B - H)
	n	Average Weaning Weight	n	Average Weaning Weight	
2	48	356	52	326	29.9
3	67	369	82	355	14.1
4	99	404	129	370	34.4
5	95	414	117	395	18.9
6	88	435	98	397	37.8
7	70	438	78	406	31.5
8	38	442	42	400	41.6
9	37	452	37	396	55.6
10	19	447	18	407	40.0
11	16	440	20	398	42.0
12 & up	8	393	12	395	-2.4

Variation over all ranches and years and within ranch-year subclasses was greater among the bull calves than among the heifers (Table X). The standard deviations for bulls and heifers were 46 and 43 pounds, respectively. The bull calves were also 34 pounds heavier at weaning. In the data suitable for the sex of calf analysis the bulls averaged 409 pounds while the heifers averaged 375 pounds. Variation within each sex was positively associated with the mean as indicated by the coefficients of variation. An evaluation of the variation, means and coefficients of variation suggests that a multiplicative factor,  $\bar{X}_B/\bar{X}_H$ , would be the best method of sex adjustment. However, to compare the effectiveness of different methods of adjustment under these conditions both the multiplicative and additive factors were used. The ratio of means was computed for each ranch and year (Table XI) to obtain the multiplicative factors. The additive adjustment factor was computed from the average weaning weight of the bull and heifer calves.

The test of significance of sex differences in the analysis of variance for additive and multiplicative sex adjusted weaning weights is shown in Table XII. The between sex mean square was not significant when either method of sex adjustment had been used. However, the multiplicative adjustment resulted in the greatest reduction in the mean square. The additive sex adjustment reduced the between sex mean square by 60 percent while the multiplicative factors brought about a 78 percent reduction.

TABLE X. VARIATION WITHIN SEXES

Source of Variation	Bulls		Heifers	
	d.f.	Mean Square	d.f.	Mean Square
Total	584	----	684	---
Ranch-Year Subclasses	85	13,183	85	8,772
Within Ranch-Year	499	2,146	599	1,803
Means	409		375	
Standard Deviation (within ranch-year)	46.32		42.46	
Coefficient of Variation	11.19		11.11	

TABLE XI. RATIO OF BULL TO HEIFER MEANS BY RANCH AND YEAR

Ranch	Year	$\bar{X}_B/\bar{X}_H$	Ranch	Year	$\bar{X}_B/\bar{X}_H$
1	52	.9755	10	57	1.1016
1	53	.8653	11	55	1.0339
1	55	1.0859	11	56	1.1311
1	56	1.1234	11	57	1.1467
1	57	1.0831	12	56	1.0905
4	57	1.1020	12	57	1.1641
5	56	1.0913	14	57	1.1394
5	57	1.1131	18	56	1.1362
9	55	.9890	18	57	1.1509
9	56	.9703	21	56	1.0728
9	57	1.1198	21	57	1.0201

TABLE XII. ANALYSIS OF VARIANCE OF SEX DIFFERENCES

Source of Variation	d.f.	Mean Square	F
Additive Sex Adjustment Applied			
Total	1269		
Ranch-Year-Age of Dam	85	19,223	9.81**
Sex Within Ranch-Year-Age of Dam	86	2,723	1.39
Error	1098	1,959	
Multiplicative Sex Adjustment Applied			
Total	1269		
Ranch-Year-Age of Dam	85	27,467	12.72**
Sex Within Ranch-Year-Age of Dam	86	1,541	
Error	1098	2,159	

\*\* Highly Significant ( $P < 0.01$ ).

#### Age of Dam

The maximum producing ability of the cows as measured by the averages of all records made at each age (Method A) appeared to be reached at eight years of age (Table XIII). Weaning weights were lowest among calves from two-year-old cows and showed the largest change between the ages of two and three years. The mean weaning weight increased at an apparent diminishing rate from two to six years of age and showed a uniform decline between the ages of nine and 12 years. Little difference was found between the average weaning weight of calves from six to nine-year-old cows. Age of dam differences within ranch-year subclasses were significant at the 0.01 level of probability (Table XIV).

TABLE XIII. AGE OF DAM MEANS BY RANCH AND YEAR

Ranch	Year	2	3	4	5	6	7	8	9	10	11	12	13
1	55		403	435			452						
1	56		388	433	413	410							
1	57	360	326	407	433	406	435		428				
2	56		381	387	418	428	397						
2	57			405	444	422	417						
3	56		429	438	438	484	445						
3	57		386	399	401	435	398	437	407				
4	57		352	371	422	452	414	438			446		
5	56		418	444		476							
5	57		398	363			400						
6	57		420		498	490	467						
7	57	326	326	343	350			310		316			
8	53				460	472		449					
8	56			475	451	455	491	496	500	460			
8	57		478	440	466	446	449	460	467	456			
9	55	351	338	418	397	387		398	422				
9	56		365	353	391	365			370	349	308		
9	57		384	386	365	429	409			409	417	357	
10	57		302	357	346	379		396	380	362			362
11	55	298	383	384	407	414	384	408	398			394	359
11	56		420	450	447	455	464	438	463	477			438
11	57			451	483	485	484	488	452	463	483		407
12	54			403	393	447	447	456	431	424	408		
12	56		363	394	396	413	404	418	432	427	404		
12	57		470	457	467	467	486	488	501	488	507	476	
14	57	400	402	377	369			491	456	450	422	420	
15	57	411	456	439									
16	57		457	421		428	415	438	400		434		437
17	56									403	388	392	400
18	56	386		437	421	441	462	471	437	456			417
18	57		459	451	472	458	492	485	443		451		
19	57	338	384	439			428						
20	57				370	412						364	381
21	56	376	396	401			426	441	428		435	409	
21	57		404	394	417			423	405	430		409	
Averages		361	396	411	420	437	438	441	433	425	417	403	400

TABLE XIV. ANALYSIS OF VARIANCE FOR AGE OF DAM EFFECTS

Source of Variation	d.f.	Mean Square	F
Total	2022		
Ranch-Year-Age of Dam:			
Ranch-Year	34	104,346	61.67**
Age of Dam Within Ranch-Year	194	4,133	2.44**
Error	1794	1,692	

\*\* Highly Significant ( $P < 0.01$ )

By comparing the weaning weight records of consecutive calves from the same cow (Method B) similar differences in age of dam were found. Again, maximum production appeared to be reached at eight years of age. Differences in the means of the age of dam groups are expressed as deviations from the eight-year-old means in Table XV. As would be expected the deviations computed by method B are smaller than those computed by method A among the young cows while the reverse is true for cows older than eight years. The standard errors associated with the deviation estimates were consistently smaller for method A since substantially larger numbers were represented in the means presented. Numbers were not considered adequate for calculating deviations for the age groups above 10 years.

Table XV also gives the estimates of age of dam effects obtained by combining the values of method A and method B. The differences between methods A and B were proportioned as  $\frac{p}{1-p}$  to obtain the combined estimates. The value  $p$  is approximated by the repeatability of adjacent weaning weights. From another analysis of these data  $p$  was estimated as 0.42.

TABLE XV. CORRECTION FACTORS FOR AGE OF DAM

Age of Dam	Deviation Method A	Deviation Method B	Combined Estimate where $p/1-p = .42/.58$
2	80 $\pm$ 5.34	54 $\pm$ 9.09	71
3	45 $\pm$ 3.08	17 $\pm$ 4.75	35
4	30 $\pm$ 2.67	8 $\pm$ 3.29	22
5	21 $\pm$ 2.56	2 $\pm$ 3.17	14
6	4 $\pm$ 3.02	3 $\pm$ 4.03	4
7	3 $\pm$ 3.08	4 $\pm$ 4.37	3
8	0	0	0
9	8 $\pm$ 4.59	10 $\pm$ 5.96	9
10	16 $\pm$ 5.29	32 $\pm$ 8.64	22
11	24 $\pm$ 5.33	---	24
12	38 $\pm$ 7.72	---	38
13 $\pm$	41 $\pm$ 7.58	---	41

## Season of Birth

The number of calves dropped during each month of the calving season and the average age adjusted weaning weight of each group is given in Table XVI. Only six calves were born during the period October 1 to December 31 so reliable estimates for these months were not available. Most of the calves were born during the months of February through June. Calves dropped in February weaned heaviest while August dropped calves were lowest in weaning weight. The relationship between weaning weight and season of birth, expressed in months, is shown graphically in Figure 1.



TABLE XVI. SEASON MEANS

Season of Birth	Number of Animals	Average Weaning Weight
1 (Jan.)	16	450
2 (Feb.)	108	464
3 (Mar.)	710	451
4 (Apr.)	979	434
5 (May)	351	424
6 (June)	124	407
7 (July)	40	417
8 (Aug.)	7	372
9 (Sept.)	10	448

The x's represent the average weight of all calves born in each month. The straight line drawn in the figure is the linear regression of weight on age at weaning. Except for the month of September the figure indicates a near additive effect of season of birth. Calves born late in the season were as much as 90 pounds lighter than calves born in February. The mean presented for September is based on only 10 records and, therefore, might differ widely from the true season effect.

The analysis of variance for weaning weight with respect to season of birth is shown in Table XVII. The between seasons mean square was calculated within ranch-year subclasses and was significant at the 0.01 level. The regression of weaning weight on season of birth is given in Table XVIII. The average regression over all ranches and years was -11.56 while the intraclass regression coefficient was -13.13.

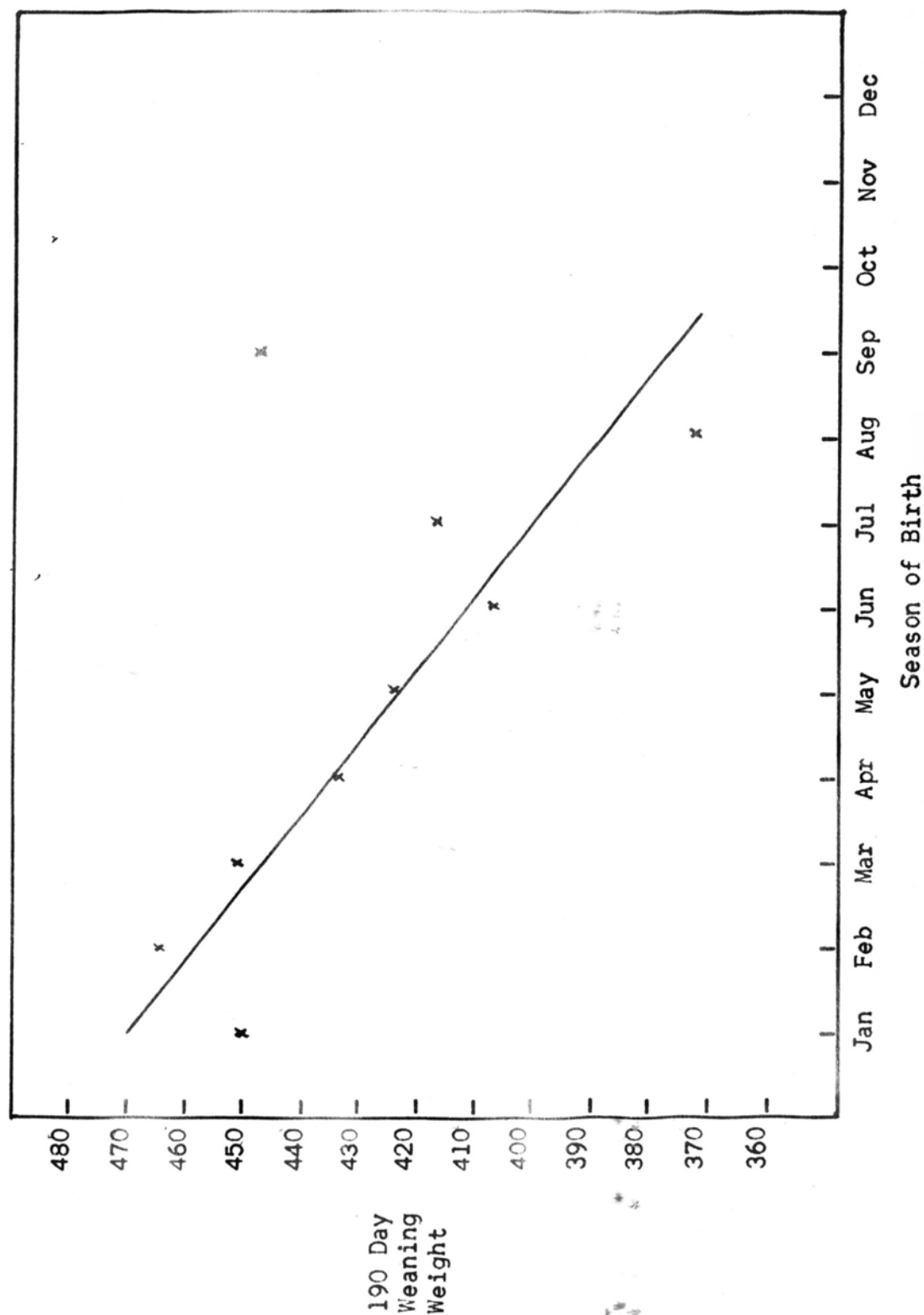


Figure I. Relation of Weaning Weight to Season of Birth

TABLE XVII. ANALYSIS OF VARIANCE FOR SEASON OF BIRTH

Source of Variation	d.f.	Mean Square	F
Total	2350		
Ranch-Year Subclasses	41	61,308	
Season Within Ranch-Year	147	5,977	3.12**
Error	2162	1,916	

\*\* Highly Significant ( $P < 0.01$ )

TABLE XVIII. REGRESSION OF WEANING WEIGHT ON SEASON OF BIRTH

Source of Variation	Season X	XY	Weaning Weight Y	b <sub>y·x</sub>
Total	3,132	- 36,216	7,535,867	- 11.56
Ranch-Year Subclass	897	- 6,871	2,513,624	
Within Ranch-Year	2,235	- 29,345	4,143,570	- 13.13

#### Repeatability of Weaning Weight

A summary of the analysis of variance of dam influence on weaning weight is given in Table XIX. The weaning weight records used in this analysis were adjusted for differences due to age, sex of calf and year effects. The mean square for the variance among dams within ranches was highly significant, the F value being 2.68. For estimating repeatability of weaning weight the within ranch variance was partitioned into a mean square between dams and an error mean square or variance among calves from the same cow. In terms of variance components, repeatability is the intraclass correlation among records by the same cow,  $\frac{\sigma_D^2}{\sigma_D^2 + \sigma_E^2}$ .

TABLE XIX. ANALYSIS OF VARIANCE FOR DAM EFFECTS

Source of Variation	d.f.	Sums of Squares	Mean Squares	Expected M.S.	F
Total	865	2,295,207			
Age of Dam	11	282,660			
Ranches	9	396,120			
Dams Within Ranches	368	1,088,878	2,959	$\sigma_E^2 / k \sigma_D^2$	2.68**
Error	477	527,549	1,106	$\sigma_E^2$	

\*\* Highly Significant ( $P < 0.01$ )

The  $\sigma_D^2$  is the variance of dam effects and  $\sigma_E^2$  is the error or variance among calves from the same cow. The expected value of the mean square among cows is  $\sigma_E^2 / k \sigma_D^2$ , where  $k$  is the average number of calves in each dam subclass. The method of estimating  $k$  is outlined by Snedecor (1956) and in this study  $k$  was 2.29. Substituting the mean squares from the analysis of variance table and 2.29 for  $k$ , the following estimate of repeatability was obtained:  $\sigma_D^2 = \frac{2,959 - 1,106}{2.29} = 809$  and repeatability =  $\frac{\sigma_D^2}{\sigma_D^2 + \sigma_E^2} = \frac{809}{1,915} = 0.42$ . The 95 percent confidence interval of the intraclass correlation was estimated according to Fisher (1950). The lower limit is 0.37 and the upper limit is 0.48.

#### Heritability of Weaning Weight

The paternal half-sib analysis of variance summary is presented in Table XX. The weaning weight records used in calculating the heritability estimate were adjusted for differences due to age, sex of calf and age of dam. The variance among sires was estimated within ranch-year

TABLE XX. PATERNAL HALF-SIB ANALYSIS OF VARIANCE

Source of Variation	d.f.	Sums of Squares	Mean Squares	Expected M.S.	F
Total	2350	7,535,867			
Ranch-Year Subclass	41	2,513,624			
Sires Within Ranch-Year	118	551,960	4,678	$\sigma_E^2 + k \sigma_S^2$	2.29**
Error	2191	4,470,283	2,040	$\sigma_E^2$	

\*\* Highly Significant ( $P < 0.01$ )

subclasses. The mean square between sires within subclasses was highly significant. The F value in this analysis was 2.29 while the corresponding value of  $F_{.01}$  was 1.37.

To obtain the components of variance necessary for computing the heritability estimate the intraclass variance was divided into two mean squares, a between sires and an error or within sires mean square. The theoretical expectation of the intraclass mean square is given in Table XX. With random mating assumed, epistatic effects negligible and environmental correlations removed the heritability estimate is  $\frac{4 \sigma_S^2}{\sigma_S^2 + \sigma_E^2}$ . The value of  $\sigma_E^2$  can be obtained directly from the analysis of variance table. The theoretical value of the sire mean square is  $\sigma_E^2 + k \sigma_S^2$ . In these data k was estimated as 14.65.

Using the mean squares from the analysis of variance table and substituting 14.65 for k, heritability can be estimated as follows:

$$\sigma_S^2 = \frac{4,678 - 2,040}{14.65} = 180 \text{ and heritability} = \frac{4(180)}{180 + 2,040} = 0.32. \text{ The}$$

fiducial limits of the heritability estimate were computed as outlined by Crump (1951). The lower limit is 0.21 and the upper limit is 0.47.

## DISCUSSION AND CONCLUSIONS

The purpose of this study was to estimate the influence and the relative magnitude of the genetic and environmental factors affecting weaning weights in beef cattle. The heritability of weaning weight was estimated by the method of paternal half-sib correlation. The non-genetic or environmental factors studied were age of the calf at weaning, sex of calf, age of dam and season of birth. Numbers included in the study are large enough to permit reasonably accurate estimates of the genetic and environmental factors studied.

Weaning weight records from the two breeds represented in these data were pooled for all statistical analyses. Separate analyses were not made for each breed since so few of the available records were from Angus herds. A comparison of the means indicated that differences between the breeds with respect to the variables studied were not large. If differences between the breeds do exist the results obtained would be more applicable to Hereford cattle since the Angus records make up such a small part of the data.

The statistical analysis of the data has shown that the age of the calf at weaning has a highly significant effect on its weaning weight. The linear regression of weaning weight on age within ranch-year-season subclasses was 1.20. This value for the intraclass regression of weaning weight on age is generally smaller than those reported by other workers. Koger and Knox (1945b) reported an intraclass regression coefficient of 1.33. Botkin and Whatley (1953) found the regression of weaning weight on age to be 1.43. An intraclass regression of 1.44 and 1.09 was reported

for bull and heifer calves, respectively by Pahnish, et al. (1958).

It was not the purpose of this study to develop age adjustment factors from the available data but to evaluate two methods of calf age adjustment already in use. The two methods evaluated in this analysis have been outlined previously. The basic difference in the two methods appears to lie in the fact that one method, age adjustment No. 1, is based on the growth rate of the individual calf while the other method, age adjustment No. 2, also takes into account the average of the group being considered.

The absolute accuracy of both methods is dependent on the linearity of growth during the range in age covered by the adjustment. The two methods yield adjustment factors computed either from individual growth rate from birth to weaning (No. 1) or from the linear regression of weight on age (No. 2). Growth has been found, in most instances, to be linear or nearly so within selected and relatively short periods from birth to eight months of age. However, the range in calf age encountered in these data was quite large and it is unlikely that growth is linear for such a wide range.

Preliminary examination of the data indicated that the weaning weights were over-adjusted by method No. 1. That is, the adjusted weights of very young calves actually exceeded what the calf would have weighed if he grew normally to the constant age. The adjusted weights of the very old calves appeared to be smaller than would be expected if the weights were taken at 190 days of age. It has been shown by Johnson and Dinkel (1951) that the growth of calves raised under similar conditions was near linear from birth to approximately 155 days of age and thereafter increased

at a decreasing rate. On the basis of this information two sets of factors were developed for the young calves, the first factor adjusted the weight to 155 days of age and the second one adjusted the weight further to 190 days. If a similar growth pattern is characteristic of the calves represented by these data, then adjustment factors based on the growth rate of individual calves would be expected to over-adjust the weight of calves from the extreme age groups.

Age adjustment No. 2 appeared to be more effective in making accurate adjustment for differences in weaning age. However, the analysis of variance and intraclass regression of weight on age show the difference in the effectiveness of the two methods to be quite small. Neither method reduced variation among calf age groups to a non-significant level nor completely removed the positive association between weight and age. The explanation for the adjustments not being more effective might lie in the fact that the range in calf age was quite large in these data; more than 250 days separated the extremes. The factors used in method No. 2 were not developed for calves above 225 days of age. Non-linearity of growth during the period covered would lessen the efficiency of either method of age adjustment.

The influence of sex on weaning weight was evaluated by two methods, a simple additive adjustment and a multiplicative adjustment factor representing the ratio of bull to heifer means. Separate multiplicative factors were computed for each ranch-year subclass. A preliminary evaluation of within sex variance, means and coefficients of variation suggested the use of a multiplicative factor. However, since they were convenient to apply



both types of adjustment were compared under the conditions implied.

The positive association of the variance and mean, as indicated by the identical coefficients of variation in Table X, suggests that heavier calves would exhibit larger sex differences. Since mature cows produce calves that are generally heavier than calves from young, immature cows, it might be expected that sex differences would be related to age of dam. An examination of the data does not substantiate such an association. The sex means by age of dam classes in Table IX show sex differences to be slightly larger for the older cows. However, the statistical analysis indicates a non-significant age of dam by sex interaction.

The additive adjustment of 34 pounds developed in this analysis is intermediate in the range of sex differences reported in the literature. Factors reported under somewhat similar conditions range from 22 pounds (Burgess, et al. 1954) to 44 pounds (Koch, 1951). Koch and Clark (1955) found a difference of 26 pounds between bulls and heifers while a difference of 38 pounds was reported by Chambers, et al. (1956) and McCormick, et al. (1956). The over-all ratio of means derived from these data was 1.082. This value is in close agreement with the ratio of 1.073 reported by Koch, et al. (1959). However, the ratio of means varied considerably from ranch to ranch and among years on the same ranch.

The data analysis indicates that a multiplicative type sex correction factor would be most suitable with these specified conditions of variance and its relationship to the mean. The multiplicative type adjustment was considerably more effective than the additive adjustment, as indicated in Table XII. However, because of rather wide differences between ranches, a multiplicative factor calculated within each herd is suggested.

For weaning records collected under conditions similar to those reported here, the use of the over-all ratio, 1.082, as a constant multiplicative factor should be more accurate than an additive factor. This analysis indicated the efficiency of the over-all ratio of means was between the two factors described but much nearer the multiplicative factor reported. Caution should be used in applying these factors to calves raised under conditions far different from those experienced by calves used in this study.

The estimates of sex differences presented here may be biased slightly by selection. In some of the herds a few bull calves were castrated sometime prior to weaning for reasons unknown. The actual number of bull calves castrated was not readily available from the weaning records. However, the total number would represent a very small percent of male calves born. The extent of the bias is probably reduced further since the decision to castrate may have been, in many cases, based on factors other than growth. The decision to castrate may have been made on breed type, color markings, conformation, dwarfism and other factors peculiar to each herd.

Consistent with the results of previous research this study indicates that the weaning weight of a calf is significantly influenced by the age of its dam. The effect of cow age was estimated by two different methods and the estimates were combined according to Lush and Shrode (1950) to obtain the best estimate of true age of dam effect.

The age of dam adjustment factors obtained from these data are in reasonable agreement with most published reports, generally falling intermediate in the range of estimates. Eight years was reported as the age

of maximum production by Sawyer, et al. (1948) and Rollins and Guilbert (1954). Burgess, et al. (1954), Nelms and Bogart (1956) and McCormick, et al. (1956) found that maximum production was reached during the years six to 10. Koch and Clark (1955) found six years and Marlowe and Gaines (1958) reported seven years as the age of maximum production. These factors are in close agreement with the age of dam factors presently being used at the South Dakota station.

The weaning weight averages increased at an apparently diminishing rate from two to six years of age with the greatest change in weight between the ages of two and three years. The mean weaning weight showed a uniform decline between the ages of nine and 12 years. There was no apparent decline in weight of calves from cows older than 12 years. Similar observations were made by Botkin and Whatley (1953) and Brown (1958). The lack of decline in production among the old cows is probably the effect of selection in the herd. The few cows remaining in the herds beyond the age of 12 years must have survived many years of culling and would of necessity represent the very best producers of their age group.

The combined estimate of the true age of dam deviations were used as the adjustment factors in this analysis. However, deviations as small as those found for the six and seven-year-old cows may be disregarded without seriously affecting the accuracy of age of dam adjustment. For practical application and convenience of computation the factors obtained may be rounded to the nearest five-pound break. The following age of dam adjustment factors are suggested as practical and reasonably accurate under conditions similar to those reported in this study.

Age of Dam:	2	3	4	5	6	7	8	9	10	11	12/
Factor:	70	35	20	15	0	0	0	10	20	25	40

The preliminary examination and statistical analysis of the data have shown that the weaning weight of beef calves is significantly influenced by season of birth. These findings are in general agreement with those of Rollins and Guilbert (1954), Nelms and Bogart (1956) and Marlowe and Gaines (1958). The results obtained here do not agree with the findings of Koch and Clark (1955). They estimated the influence of season by regressing weight on age at weaning within year and obtained a regression coefficient of  $-0.04$  pounds per day ( $P < 0.05$ ). The regression indicated that calves born early in the season did not grow quite as rapidly as calves born later. However, the regression was not significantly different from zero.

Although the differences obtained for season of birth were highly significant, no season of birth adjustment factors were applied to these data for estimating sex of calf and age of dam effects. Estimating the effects of several environmental factors individually requires that some order be established. The effects of sex and age of dam were estimated first because it was expected that the effects of these would be larger than season effects. Since season of birth would not be expected to differentially influence sex or age of dam estimates, it was disregarded in making these analyses. Comparison of the two methods of calf age adjustment was made after season effects were estimated. The age of calf regression analysis was made on a within season basis.

In order that calves dropped in different seasons of the year may be more accurately compared, the influence of season of birth should be

recognized and discounted as accurately as possible. Additive adjustment factors for season of birth were obtained from this study. The factors were arrived at by taking the February average as a base for comparison since production in this period appeared to be maximum. The following factors were suggested from this analysis.

Month of Birth:	Jan.	Feb.	Mar.	Apr.	May	June	July
Factor:	10	0	10	30	40	55	45

Weaning weight records for other months were not considered adequate in number to provide reliable estimates of season effect. In areas where calving is purposely restricted to the period from late winter to early summer most calves will probably be dropped within the period covered by these factors.

The accuracy of the season effects obtained in this analysis is unknown since it was not possible to completely separate season effects from age of calf effects. When all calves in a herd are weaned on the same day, season of birth is automatically confounded with age of calf. Therefore, any estimate of season effect may also include some calf age influence.

The repeatability estimate of 0.42 obtained from the present study is in fairly close agreement with estimates from other studies, being intermediate in the range of repeatability estimates reported. Koch (1951) estimated the repeatability of weaning weight in range beef cattle at 0.52. Botkin and Whatley (1953) obtained estimates of 0.43 and 0.49. An estimate of 0.49 was reported by Koger and Knox (1947) and Gregory, et al. (1950) estimated repeatability at 0.37 to 0.50. Rollins and Wagnon (1956) estimated repeatability at 0.51 in a herd operated under

optimum nutritional conditions and 0.34 under sub-optimum conditions.

The repeatability fraction includes all effects due to permanent differences among cows. Since some of the permanent differences between cows may be non-transmissible, repeatability will always be at least as great, and probably greater, than heritability. Repeatability sets an upper limit to the heritability of the maternal influence on weaning weight. Since both repeatability and heritability were estimated from the same data, a direct comparison of the two values is possible. The estimates obtained from this study indicate that heritability (0.32) is about 75 percent of repeatability (0.42). Lush and Arnold (1937) obtained both estimates from the same data for butterfat production in dairy cattle. In their study heritability (0.28) was about two-thirds of repeatability (0.43).

Knowledge of the repeatability of adjacent weaning weight records of the same cow is important to effective selection for cow production. The younger the cow when her producing ability can be measured accurately, the more efficient selection can be. Lush (1949) has shown the most probable producing ability of the cow to be herd average  $\frac{nr}{1 + (n-1)r}$ , X her own average - herd average, where n is the number of records and r is the repeatability of the trait being considered. The fraction  $\frac{nr}{1 + (n-1)r}$  indicates how much confidence can be placed in the cow's record as an indication of her real producing ability.

The relatively high repeatability of weaning weights obtained in this study indicates that selection for high producing cows can be practiced early in their producing life. Since cows at either extreme, either very high or very low producers, contribute much more to the

repeatability of weaning weights than those near the average, the very low producers can be culled on the basis of their first records with little risk of culling good cows. If only a small proportion of the producing cows are to be culled, the first record should be reasonably accurate. The application of the repeatability estimate presented should be limited to those situations where cattle are handled under conditions similar to those from which the estimate was obtained.

Heritability has been described by Lush (1949) as a quantitative expression of the extent to which differences between individuals are caused by differences in the heredity they have. In the narrow sense it is the fraction of differences between parents which we can expect to recover in their offspring. In terms of variance components, heritability is the ratio of genetic variance to total observed variance.

Heritability of weaning weight is important to the breeder of range beef cattle. In many beef cattle herds the initial selection of replacement females is made at weaning and quite often final selection is practiced at this time. The magnitude of the heritability estimate should influence his decision in choosing the best methods of selection and the most suitable breeding plan. The relative emphasis to be given to individual traits should be determined by the heritability of the trait. Dependable estimates of heritability are necessary in order to accurately estimate the rate of progress in a selection program.

Of the several methods available for estimating heritability only the paternal half-sib correlation method was applicable to these data. An analysis of the data has shown the influence of sire on weaning weight to be highly significant. The size of the sample studied and the comparatively



large number of sires represented should give fair precision to the estimate. This is further indicated by the rather narrow range of fiducial limits obtained.

The paternal half-sib correlation estimate of heritability obtained in this study agrees reasonably close with those reported from other studies. The present estimate of 0.32 probably falls close to the upper end of the range of reported heritability estimates. Estimates have ranged from 0.23 and 0.24 reported by Shelby, et al. (1955) and Koch and Clark (1955a), respectively to 0.36 found by Dinkel and Musson (1956). Estimates of 0.26 were obtained by Gregory, et al. (1950) and Brown (1958) while Knapp and Nordskog (1946) and Chambers, et al. (1958) reported estimates of 0.30.

Improvement in beef cattle production is dependent on the magnitude and nature of the variation present in the production traits. Information necessary for effective herd improvement includes knowledge of the influence of specific environmental factors and the relative importance of heredity on the expression of the performance traits in question. Calf weaning weight is one of the most important economic traits in range beef production. It affords the breeder useful information for evaluating cow production and for selecting replacements to go into his herd. Accurate evaluation of calf weaning weight and the relative emphasis to be given weaning weight in a selection program depend on an adequate understanding of the several environmental and genetic factors that may affect the weight of beef calves at weaning.

Any one of several environmental factors, if not recognized and discounted, can cause the breeder to make serious errors in culling poor



producers or selecting replacements. Since it is not generally feasible to weigh each calf as it reaches a constant age, correction for differences in calf age at weaning is necessary. In addition to the adjustment of calf weights to a standard age, they should also be adjusted for differences due to sex of calf, age of dam and, possibly, season of birth. Adjustment factors for the above influences were obtained from these data and are recommended for beef cattle handled under conditions similar to those reported here.

With the major environmental influences recognized and adequate adjustments made, the breeder still needs to know how much of the variation in calf weaning weights is heritable. This information along with knowledge of the total variation present allows him to estimate the rate of progress possible in a selection program. The estimate of heritability obtained from this study indicates that selection for weaning weight can be expected to bring about substantial improvement in the trait. The ultimate improvement in the weaning weight of beef cattle will be governed largely by the breeder's willingness to keep complete production records, adjusted for known environmental influences, and make his selections on the basis of those records.

## SUMMARY

Several factors that are known to influence the weaning weight of beef calves were evaluated in this study. The factors evaluated were age of calf at weaning, sex of calf, age of dam and season of birth. With the records standardized for the above influences repeatability of adjacent weaning weights was determined. The paternal half-sib correlation estimate of heritability was also obtained from the data. The genetic and environmental factors studied were evaluated individually by conventional analysis of variance procedures.

The data utilized in this study included the weaning weights of 2351 calves representing 120 bulls from 20 purebred Hereford and Aberdeen-Angus herds in South Dakota. The data were collected from 1951 through 1957 in cooperation with the South Dakota Extension Service.

Age of calf at weaning was shown to have a highly significant influence on its weaning weight. The linear regression of weight on age within ranch-year-season subclasses was 1.20. Two methods of calf age adjustment were evaluated. One method, adjustment No. 1, was based on the individual growth rate and the second method, adjustment No. 2, also considered the average growth rate of the group. Age adjustment No. 2 appeared to be the most efficient, removing 90 percent of the variance due to age of calf. Failure to achieve greater accuracy is probably due to the wide range in calf age found in these data.

Two methods of sex adjustment were compared in this study, an additive factor and a multiplicative factor based on the ratio of sex means. For the additive adjustment 34 pounds was added to each heifer

weight. The ratio of means was computed for each ranch and year. The multiplicative adjustment factor used appeared to be the most effective, accounting for 78 percent of the sex variance compared to a 60 percent reduction for the additive factor.

Analysis of the data indicated age of dam influence on weaning weight was highly significant. Weaning weights were lowest among calves from two-year-old cows and showed the largest change between the ages of two and three years. Maximum production was reached at eight years of age. Age of dam adjustment factors were computed by two methods, by averaging all records made at each age and by comparing the records of consecutive calves from the same cow. The factors developed by the two methods were then combined to obtain the estimate of age of dam effect. The adjustment factors obtained in this study were in reasonably close agreement with other factors reported.

Season of birth was shown to have a highly significant effect on calf weaning weight. Production appeared to be highest among the calves born in February. The average weaning weights declined through the spring and summer months with the lighter calves being dropped in mid-summer. The intraclass regression of weaning weight on month of birth was -13.13.

The influence of dam on calf weaning weight was highly significant in this study. The weaning weights were adjusted for differences due to age and sex of calf and for year effects. The mean square for variance among dams was then calculated on a within ranch basis. Repeatability of weaning weight was estimated as the intraclass correlation of adjacent weaning weight records of the same cow. The correlation was

estimated as  $\frac{\sigma_D^2}{\sigma_D^2 + \sigma_E^2}$ , where  $\sigma_D^2$  is the variance of dam effects and  $\sigma_E^2$  is the error or variance among calves from the same cow. The repeatability estimate obtained from this study was 0.42. The upper limit of the confidence interval was 0.48 and the lower limit was 0.37. The repeatability estimate obtained is considered high enough that selection for high producing cows or the culling of low producers could be practiced early in the cow's producing life. If a small proportion of the producing cows are to be culled the first record should be reasonably accurate, so the very low producers could be culled with little risk of culling good cows.

Heritability of weaning weight was estimated by the paternal half-sib correlation method as outlined by Lush (1940). The analysis of variance was applied to the weaning weights of 2351 calves representing 120 sires. The data were collected on twenty private ranches over a seven-year period. The mean squares used in obtaining the estimate were calculated within ranch-year subclasses. The intraclass correlation among half-sib groups was calculated as  $\frac{\sigma_S^2}{\sigma_S^2 + \sigma_E^2}$ , where  $\sigma_S^2$  is the sire variance and  $\sigma_E^2$  is the variance among calves from the same sire. Heritability of weaning weight was estimated at 0.32 from the half-sib analysis of these data. The fiducial limits of the heritability estimate were computed as outlined by Crump (1951). The lower limit is 0.21 and the upper limit is 0.47. The heritability estimate obtained in this study is in general agreement with those reported by other workers. The magnitude of the heritability estimate indicates that selection should bring about improvement in the weaning weight of beef cattle.

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